per second, or about seventy times the possible transmission. Of course there would be some loss by absorption in the media of the eye, and, again we may not limit the refractory interval as we have done. It might be ten times smaller and yet not fall below the value apparently associated with audition. But even so, we must recognise that in photopic vision the flash of the electron may often come at the wrong moment and fail to evoke vision.

An important deduction from this consideration is that a highly dilute visual purple may suffice for the requirements of photopic vision. The fact that dark adaptation of the fovea is feeble supports this view.

The Effect of Red Fatigue on the White Equation.

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(Communicated by Prof. W. M. Bayliss, F.R.S. Received April 22, 1921.)

The white equation, that is the amount of pure spectral red, green, and violet, required to match a simple white, is of fundamental theoretical importance. The apparatus used in these experiments is of similar principle to that of Abney, namely, the selection of portions of the spectrum by slits and their re-combination on a white surface by means of a lens, but with several improvements suggested by Captain Fulton. The source of light is a "Pointolite" lamp of 1000 c.p. The light is focussed on the slit of a collimator, from which it emerges in a parallel beam. It is then dispersed by a compound prism of the Amici type. A lens placed close to the prism focusses the spectrum on the slits, the light being reflected by a mirror placed in the path. A second lens is constructed so as to take the whole spectrum, portions of which are isolated by means of slits. The focal length of the lens is arranged so that an image of the last surface of the prism is projected on a screen, the colour being dependent on the portion or portions of the spectrum isolated by the slits. In order to obtain a long light-path, the light is again reflected by a second mirror before reaching the screen. The intensity of a comparison patch of white light is regulated by an adjustable diaphragm placed in the path of light. The apparatus is used in a dark room free from stray light.

The three lights used in these experiments were a red of λ 6670–λ 6770 Å., a green of λ 5144–λ 5156 Å., and a violet of λ 4250–λ 4267 Å. In making the equation, the red and violet slits are kept unaltered, the equation being made by closing or opening the slit, allowing green light to pass. The size

of the portion of spectrum in the green for the normal equation is given above, and corresponds to thirteen scale divisions. The equation is very easy to make, the mean deviation being very small.

The following are the results of twelve consecutive observations by two normal-sighted persons, the equations being made alternately, starting with too much or too little green in the equation:—

A.	From green...	13	From red... 13	B.	From green... 13	From red...	12·5
		13	13		12·5		13
		13	13·5		12·5		13

One scale division at λ 515 corresponds to about 1 Å.

The screens, which are viewed at a distance of 4 feet, so that the images shall fall on the foveæ, are coated with magnesium oxide. The experiments were made in order to find out the effect of fatigue with red light, which is supposed to affect only the hypothetical red sensation.

The light used for fatigue was a "Pointolite" arc of 100 c.p. with a condenser, viewed through a deep red glass, which only allows red from λ 630 $\mu\mu$ to the end of the red end of the spectrum to pass. The light was viewed with both eyes, and care was taken that the arc should not be directly visible. An ordinary incandescent electric lamp obscured by ground glass was also used. Red isolated in my spectrometer of the region λ 670 was also used with the same result. After a certain amount of fatigue, the length of time varying with different persons, the mixed and the simple lights were viewed. There was now a striking change in the mixed white, which appeared a brilliant green, and no longer matched the simple white. In order to match the simple white, the green had to be so reduced that the mixed light appeared red to a person with an unfatigued eye. Several normal-sighted persons were then tried with the same result. Observations were taken with the equation correct for the observer, and with too much or too little green in the equation. My normal equation is: 36 red, 14 green, and 42 violet; after 5 seconds' red fatigue, the equation was: red 36, green 7, violet 42.

The following observations are by two normal-sighted persons. A, normal equation: red 36, green 13, violet 42; after 30 seconds' red fatigue, the equation was: red 36, green 8, violet 42, and the equation made was exactly the same, whether the normal equation was viewed or an equation in which there was too much or too little green. The observer did not know which was shown. B, normal equation: red 36, green 12, violet 42; after 20 seconds' red fatigue, the equation was: red 36, green 5, violet 42, when his normal equation was viewed; red 36, green 5½, violet 42, when the equation viewed at first contained too much green; and red 36, green 4, violet 42, when the equation viewed at first contained too little green.

It will be seen that, after fatigue with red, only about half as much green is required in the equation. In making these observations, it is important that the fatigue should not be too strong, as the blue-green after-effect may obscure the appearance, and prevent correct observations being taken. A man with normal colour vision, who had passed my card test, had a normal white equation, normal complementary of yellow and violet, and normal monochromatic division of yellow, after one minute's red fatigue, was quite satisfied when the green slit was quite closed or open to its full extent, the equation then appearing bright red and green respectively to a normal-sighted person. This is in accordance with the observations of A. W. Porter and myself on successive contrast,* when we found that the after-image was not affected by subsequent light falling on the retina when this was not of too great intensity. When the fatigue is great, a blue-green after-effect is seen, which is negative in colour but positive in luminosity, appearing bright on the dark ground; it appears to consist of minute particles, which move towards the centre with a whirlpool movement and then disappear. If the equation be then made, it will be found, as before, that the proportion of red is too high. A colour-blind man who put too much green in the white equation, and another who put too little, after fatigue with red put a much less amount, thus varying in the same way as the normal.

It is generally stated that, with regard to the fovea, it is found that all colour matches still remain valid, no matter what kind of light may have previously stimulated the retina. This appears to be true when red of the region λ 780 is used for the fatigue. This was obtained by viewing the light through a deep violet glass combined with a deep red glass. The two glasses only allow red of the region of λ 780 to pass. Watson† stated that colour matches remain valid after stimulation with another light, but that the mean deviation was considerably increased. This does not appear to be the case when the fatigue is not excessive. The blue-green after-effect appears to be due to the decomposition products of a photo-chemical substance (the visual purple) in the retina, and to be distinct from fatigue of the retino-cerebral apparatus. There seems to be considerable variation in the length of time necessary to cause fatigue with different persons.

These observations are quite inconsistent with the three-sensation theory. The white equation and its match cannot be due to similar physiological processes, or both would change in the same ratio.

I must express my indebtedness to Captain Fulton and Mr. Isaacs, of the Board of Trade, for their help in making these observations.

* 'Roy. Soc. Proc.,' B, vol. 85, p. 434 (1912).

† 'Roy. Soc. Proc.,' A, vol. 89, p. 235 (1913).